Study and Comparison of Different Wind Codes on a Particular Low Rise Structure

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CERTIFICATE

This is to certify that the work entitled, **"Study And Comparison of Different Wind Codes on a Particular Low Rise Structure"** submitted by **Karan Singh-071632, Himanshu Singh-071613, Swapnil Thakur-071625, Vibhor Sharma-071521 and Harcharan Singh Gill-071605,** in partial Fulfilment for the award of degree of Bachelor of Technology in Civil Engineering of Jaypee University of Information Technology has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or institute for the award of this or any other degree or Diploma.

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26/5/11

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Date: 25/05/11

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LIST OF CONTENTS

Tables & Figures Used

SYNOPSIS

Wind is the flow of gases on a large scale. On Earth, wind consists of the bulk movement of air. In outer space, solar wind is the movement of gases or charged particles from the sun through space, while planetary wind is the out gassing of light chemical elements from a planet's atmosphere into space.

In meteorology, winds are often referred to according to their strength, and the direction the wind is blowing from. Short bursts of high speed wind are termed gusts.

Origin of Winds: Wind is caused by differences in pressure. When a difference in pressure exists, the air is accelerated from higher to lower pressure. Globally, the two major driving factors of large scale winds (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet. Near the Earth's surface, friction causes the wind to be slower than it would be otherwise. Surface friction also causes winds to blow more inward into low pressure areas.

Pressure gradient is the difference in pressure between high and low pressure areas. Wind speed is directly proportional to the pressure gradient. This means the strongest winds are in the areas where the pressure gradient is the greatest.

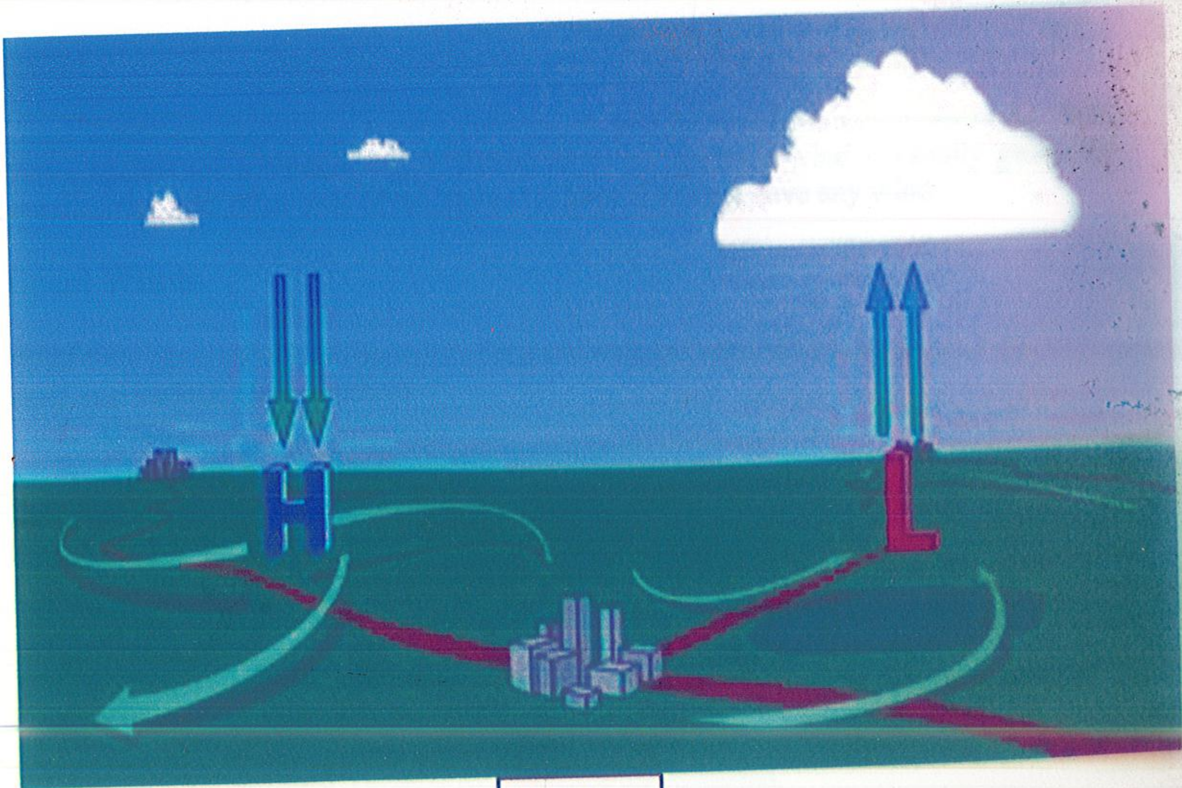

Fig. 1

However, because of the earth's rotation, there is second force, the Coriolis force that affects the direction of wind flow. Named after Gustav-Gaspard Coriolis, the French scientist who described it mathematically in 1835, this force is what causes objects in the northern hemisphere to turn to the right and objects in the southern hemisphere to turn to the left.

Types of Winds

You might think that there is only 1 kind of wind. However, because the sun shines different on each part of the world there are different types of wind. To describe air movement meteorologists have divided the earth in six parts.

Global

Global winds are the types of wind that appear all over the world because of the following reasons:
- The earth's rotation
- The earth's movement around the sun
- Because of the round shape of the world

Global winds are the large movements between the six parts of the world. They really differ from each other. Besides the three types of movements you can see on the image there are also wind phenomena, such as jet streams.

Local

Local winds are dependent on the scenery. A good example is mountain areas. Wind blows against the mountain and is forced to go up. Because wind is usually going into one direction, the other side of the mountain almost doesn't have any wind.

Local Winds

Wind flow generation is on account of atmospheric pressure differentials and manifests itself into various forms, such as

1. Gales
2. Cyclones/Hurricanes/Typhoons
3. Tornados
4. Thunderstorms

Gale

A gale is a very strong wind. There are conflicting definitions of how strong. The U.S. Government's National Weather Service defines a gale as 34 to 47 knots (63 - 87 km/h, 17.5 - 24.2 m/s or 39 - 54 miles/hour) of sustained surface winds. Forecasters typically issue gale warnings when winds of this strength are expected.

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Beaufort Scale

The Beaufort scale is an empirical measure for describing wind speed based mainly on observed sea conditions. Its full name is the Beaufort Wind Force Scale.

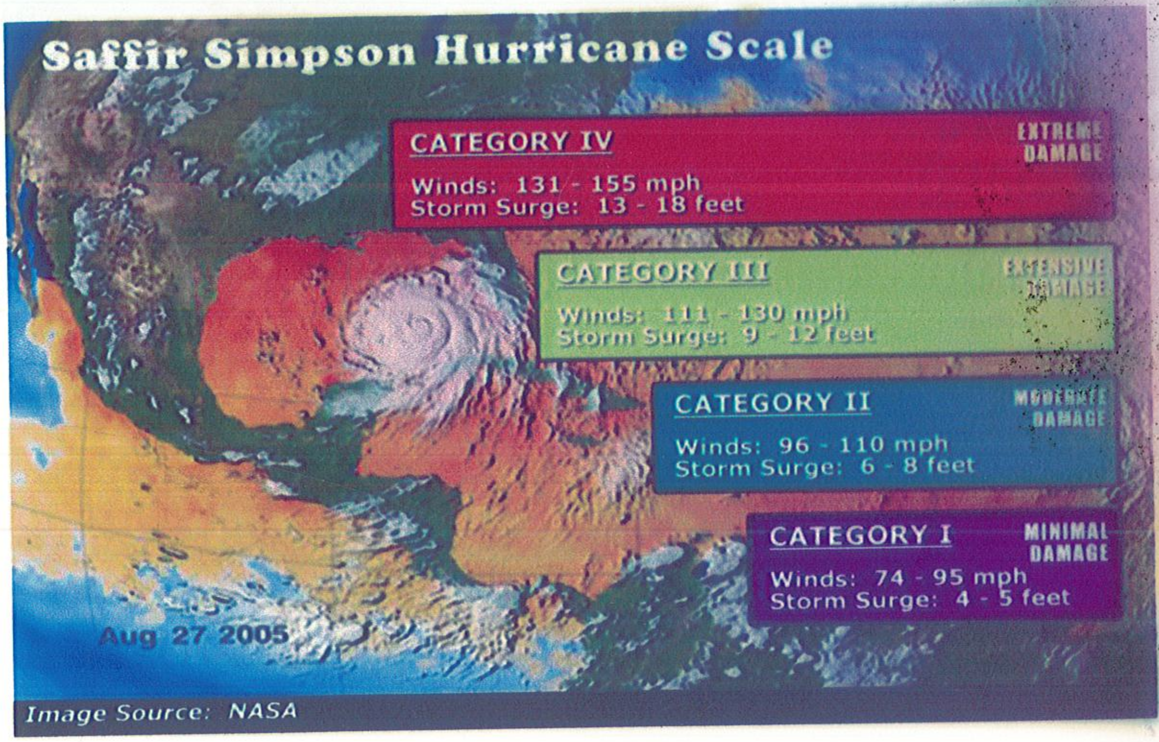
The scale was created in 1806 by Sir Francis Beaufort, an Irish-born British admiral and hydrographer. The scale that carries Beaufort's name had a long and complex evolution, from the previous work of others, to when Beaufort was a top administrator in the Royal Navy in the 1830s.

Beaufort Scale

Beaufort number	Wind Speed (mph)	Seaman's term		Effects on Land
0	Under 1	Calm		Calm; smoke rises vertically.
1	1-3	Light Air		Smoke drift indicates wind direction; vanes do not move.
2	4-7	Light Breeze		Wind felt on face; leaves rustle; vanes begin to move.
3	8-12	Gentle Breeze		Leaves, small twigs in constant motion; light flags extended.
4	13-18	Moderate Breeze		Dust, leaves and loose paper raised up; small branches move.
5	19-24	Fresh Breeze		Small trees begin to sway.
6	25-31	Strong Breeze		Large branches of trees in motion; whistling heard in wires.
7	32-38	Moderate Gale		Whole trees in motion; resistance felt in walking against the wind.
8	39-46	Fresh Gale		Twigs and small branches broken off trees.
9	47-54	Strong Gale		Slight structural damage occurs; slate blown from roofs.
10	55-63	Whole Gale		Seldom experienced on land; trees broken; structural damage occurs.
11	64-72	Storm		Very rarely experienced on land; usually with widespread damage.
12	73 or higher	Hurricane Force		Violence and destruction.

Saffir-Simpson Hurricane Scale

The Saffir–Simpson Hurricane Scale is a classification used for some Western Hemisphere tropical cyclones that exceed the intensities of tropical depressions and tropical storms. The scale divides hurricanes into five categories distinguished by the intensities of their sustained winds. In order to be classified as a hurricane, a tropical cyclone must have maximum sustained winds of at least 74 mph (33 m/s; 64 km; 119 km/h). The highest classification in the scale, Category 5, is reserved for storms with winds exceeding 155 mph (69 m/s; 135 km; 249 km/h).



Fujita Tornado Scale

The Fujita Scale is used to rate the intensity of a tornado by examining the damage caused by the tornado after it has passed over a man-made structure. The "Percentage of All Tornadoes 1950-1994" pie chart reveals that the vast majority of tornadoes are either weak or do damage that can only be attributed to a weak tornado. Only a small percentage of tornadoes can be correctly classed as violent.

ORIGINAL FUJITA SCALE		ENHANCED FUJITA SCALE	
F5	261-318 mph	EF5	+200 mph
F4	207-260 mph	EF4	166-200 mph
F3	158-206 mph	EF3	136-165 mph
F2	113-157 mph	EF2	111-135 mph
F1	73-112 mph	EF1	86-110 mph
F0	<73 mph	EF0	65-85 mph

Velocity Measurement

Wind speed is the speed of wind, the movement of air or other gases in an atmosphere. It is a scalar quantity, the magnitude of the vector of motion.

Wind speed has always meant the movement of air in an outside environment, but the speed of air movement inside is important in many areas, including weather forecasting, aircraft and maritime operations, building and civil engineering. High wind speeds can cause unpleasant side effects, and strong winds often have special names, including gales, hurricanes, and typhoons.

Anemometer

An anemometer is a device for measuring wind speed, and is a common weather station instrument. The term is derived from the Greek word *anemos*, meaning wind. The first known description of an anemometer was given by Leon Battista Alberti in around 1450.

Velocity Anemometers

They are classified as:

1. Cup Anemometer
2. Wind-mill Anemometer
3. Hot-Wire Anemometer
4. Laser Doppler Anemometer
5. Sonic Anemometer
6. Ping-Pong Ball Anemometer

Cup Anemometer

A simple type of anemometer is the cup anemometer, invented (1846) by Dr. John Thomas Romney Robinson, of Armagh Observatory. It consisted of four hemispherical cups each mounted on one end of four horizontal arms, which in turn were mounted at equal angles to each other on a vertical shaft. The air flow past the cups in any horizontal direction turned the cups in a manner that was proportional to the wind speed.

Windmill Anemometers

Windmill anemometers are based on the design of wind vanes, which simply illustrate wind direction. A windmill anemometer is more accurately described as an aero vane, which is essentially a wind vane with a propeller on it. The tailfin of the wind vane accurately displays wind direction, while the propeller at the front can record wind velocity by calculating revolutions per minute.

Sonic Anemometers

Sonic anemometers, first developed in the 1970s, use ultrasonic sound waves to measure wind velocity. They measure wind speed based on the time of flight of sonic pulses between pairs of transducers. Measurements from pairs of transducers can be combined to yield a measurement of velocity in 1-, 2-, or 3-dimensional flow.

Ping-Pong ball Anemometers

A common anemometer for basic use is constructed from a ping-pong ball attached to a string. When the wind blows horizontally, it presses on and moves the ball; because ping-pong balls are very lightweight, they move easily in light winds. Measuring the angle between the string-ball apparatus and the line normal to the ground gives an estimate of the wind speed.

Variation of Wind Velocity with height

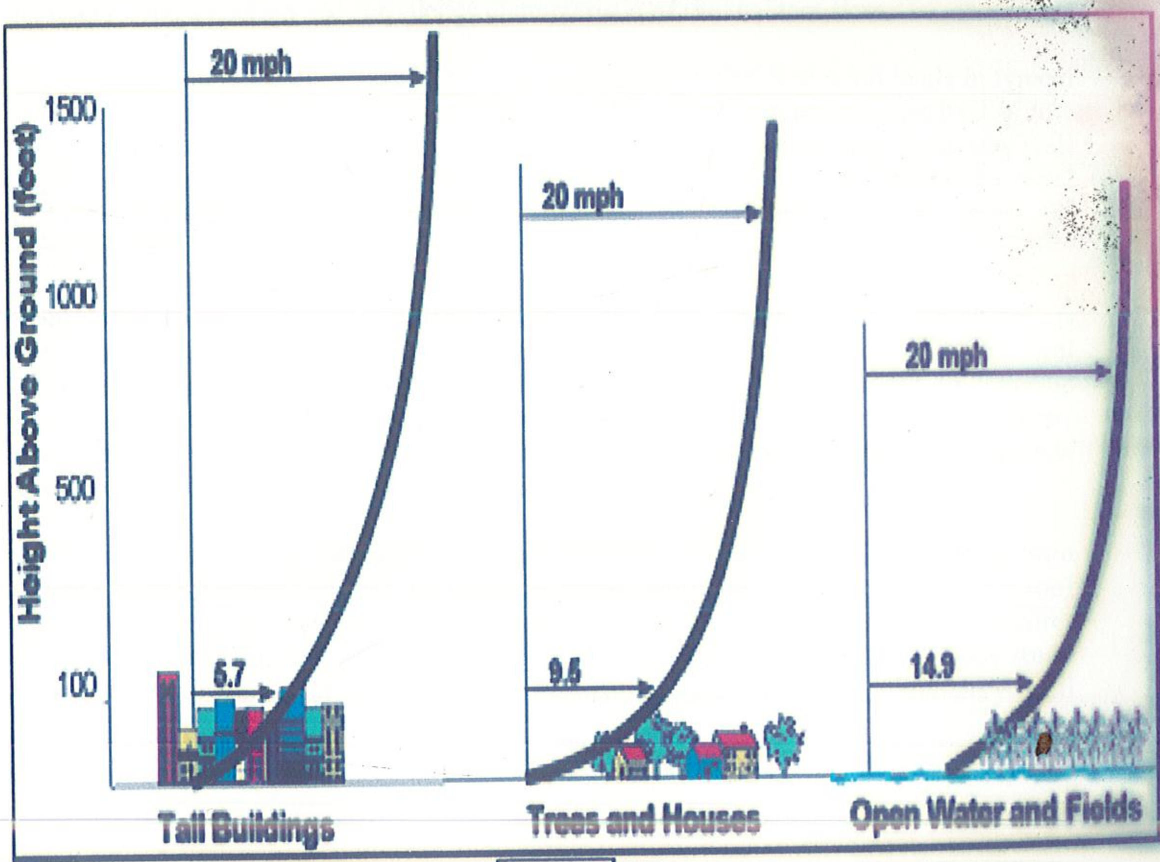


Fig. 2

Effects of Wind on Structure

Wind produces three different types of effects on structure:

Static, dynamic and aerodynamic. The response of load depends on type of structure. When the structure deflects in response to wind load then the dynamic and aerodynamic effects should be analyzed in addition to static effect.

Flexible structures and structural elements are subjected to wind induced along and across the direction of wind.

Damages caused by winds

Wind damage to low rise building for commercial, industrial and residential purposes continues to receive growing attention from researchers and engineers. Large fluctuating pressures, generated in flow separation regions close to the leading edge on the roof of low rise buildings, are a major cause of damage in windstorm. These pressure fluctuations are governed by the geometrics and orientation of buildings, relative to the prevalent wind direction and turbulence characteristic of the incident flow.

Efforts of several researches have been focused on determination of wind loads in typical low-rise buildings. A large number of various architectural features are involved in low rise buildings. Architectural features like length to width ratio of building, boundary wall etc, can modify flow pattern of wind in and around the buildings and affect the wind loads on buildings. This area of study continues to have an important scope for investigations.

Wind pressure in low rise buildings with gable roof under isolated conditions is determined using Wind codes. However, wind tunnel investigations continue to be a vital tool to investigate the pressure on common type of gable/hip roofs. Further, to cover-up the limitation of Codal practice for the influence of interference of neighboring buildings, objects and the boundary wall, the wind tunnel plays a vital role. Figure 1 shows few common types of low-rise residential buildings in India.

Determination of wind pressure in low-rise buildings with gable roofs have mostly been obtained through experimental investigations conducted on common types of gable roof buildings and limited work is being conducted to include effect of architectural features like plan aspect ratio, roof angle ,boundary wall etc. The present paper includes study on,(a)Effect of wind load on overhang because of aspect ratio and boundary wall (b)Influence of topography on wind load.

CHAPTER – 2

LITERATURE REVIEW

CODE OF PRACTICE FOR DESIGN LOAD FOR BUILDINGS AND STRUCTURES (PART 3 WIND LOADS) (IS-875 1987)

This Indian Standard (Part 3) (Second Revision) was adopted by the Bureau of Indian Standards on 13 November 1987, after the draft finalized by the Structural Safety Sectional Committee had been approved by the Civil Engineering Division Council.

This standard was first published in 1957 for the guidance of civil engineers, designers and architects associated with the planning and design of buildings. It included the provisions for the basic design loads (dead loads, live loads, wind loads and seismic loads) to be assumed in the design of the buildings. In its first revision in1964, the wind pressure provisions were modified on the basis of studies of wind phenomenon and its effect on structures, undertaken by the special committee in consultation with the Indian Meteorological Department. In addition to this, new clauses on wind loads for butterfly type structures were included; wind pressure coefficients for sheeted roofs, both curved and sloping were modified; seismic load provisions were deleted (separate code having been prepared) and metric system of weights and measurements was adopted.

TERMINOLOGY

For the purpose of this code, the following definitions shall apply.

Angle of Attack -Angle between the direction of wind and a reference axis of the structure.

Breadth - Breadth means horizontal dimension of the building measured normal to the direction of wind.

Depth - Depth means the horizontal dimension of the building measured in the direction of the wind.

Developed Height - Developed height is the height of upward penetration of the velocity profile in a new terrain. At large fetch lengths, such penetration reaches the gradient height, above which the wind speed may be taken to be constant. At lesser fetch lengths, a velocity profile of a smaller height but similar to that of the fully developed profile of that terrain category has to be taken, with the additional provision that the velocity at the top of this shorter profile equals that of the un-penetrated earlier velocity profile at that height.

Effective Frontal Area - The projected area of the structure normal to the direction of the wind.

Element of Surface Area - The area of surface over which the pressure coefficient is taken to be constant.

Force Coefficient - A non-dimensional coefficient such that the total wind force on a body is the product of the force coefficient, the dynamic pressure of the incident design wind speed and the reference area over which the force is required.

Ground Roughness - The nature of the earth's surface as influenced by small scale obstructions such as trees and buildings (as distinct from topography) is called ground roughness.

Gust - A positive or negative departure of wind speed from its mean value, lasting for not more than, say, 2 minutes over a specified interval of time.

Peak Gust - Peak gust or peak gust speed is the wind speed associated with the maximum amplitude.

Fetch Length - Fetch length is the distance measured along the wind from a boundary at which a change in the type of terrain occurs. When the changes in terrain types are encountered (such as, the boundary of a town or city,forest, etc), the wind profile changes in character but such changes are gradual and start at ground level, spreading or penetrating upwards with increasing fetch length.

Gradient Height- Gradient height is the height above the mean ground level at which the gradient wind blows as a result of balance among pressure gradient force, coriolis force and centrifugal force. For the purpose of this code, the gradient height is taken as the height above the mean ground level, above which the variation of wind speed with height need not be considered.

Mean Ground Level - The mean ground level is the average horizontal plane of the area enclosed by the boundaries of the structure.

Pressure Coefficient - Pressure coefficient is the ratio of the difference between the pressure acting at a point on a surface and the static pressure of the incident wind to the design wind pressure, where the static and design wind pressures are determined at the height of the point considered after taking into account the geographical location, terrain conditions and shielding effect. The pressure coefficient is also equal to $[1 - (V_p/V_z)^2]$, where, V_p is the actual wind speed at any point on the structure at a height corresponding to that of V_z.

WIND SPEED AND PRESSURE

Nature of Wind in Atmosphere – In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect) but this is ignored in the code. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average vaiue. The average value depends on the averaging time employed in analyzing the meteorological data and this averaging time varies from a few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust, depends on the averaging time. In general, smaller the averaging interval, greater is the magnitude of the gust speed.

Basic Wind Speed – In India basic wind speed is applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. Basic wind speeds has been worked out for a **50** year return period.

Design Wind Speed (V_z) - The basic wind speed (V_z) for any site shall be obtained from Fig. and shall be modified to include the following effects to get design wind velocity at any height (V, j for the chosen structure:

a) Risk level;
b) Terrain roughness, height and size of structure; and
c) Local topography.
It can be mathematically expressed as follows:

$$\mathbf{V_z = V_b\, k_1\, k_2\, k_3}$$

Where:
V_b = design wind speed at any height z in m/s;
k_1= probability factor (risk coefficient);
k_2= terrain, height and structure size factor; and
k3 = topography factor.

Design Wind Pressure - The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$\mathbf{p_z = 0.6\, V_z^2}$$

Where,
p_z = design wind pressure in N/ms at height z, and
v_z - design wind velocity in m/s at height z.

Pressure Coefficients - The pressure coefficients are always given for a particular 2surface or part of the surface of a building. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C,) and the design wind pressure at the height of the surface from the ground.

Wind Load on Individual Members – When calculating the wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, *F,* acting in a direction normal to the individual structural element or cladding unit is:

$$F=(C_{pe} - C_{pi})A_{pa}$$

Where;

F = Wind Load

C_{pe} = external pressure coefficient,

C_{pi} = internal pressure- coefficient,

A = surface area of structural or cladding unit, and

P_a = design wind pressure.

EURO CODE (1991)

The European Standard has been prepared by Technical Committee CEN/TC 250 "Structural Euro Codes", the Secretariat for which is held by BSI.

Background of the Euro code programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonization of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonized technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

Definitions

Fundamental basic wind velocity

The 10 minute mean wind velocity with an annual risk of being exceeded of 0, 02, irrespective of wind Direction, at a height of 10 m above flat open country terrain and accounting for altitude effects (if Required)

Basic wind velocity

the fundamental basic wind velocity modified to account for the direction of the wind being considered and the season (if required)

Mean wind velocity

The basic wind velocity modified to account for the effect of terrain roughness and orography.

Pressure coefficient

External pressure coefficients give the effect of the wind on the external surfaces of buildings; internal Pressure coefficients give the effect of the wind on the internal surfaces of buildings. The external pressure coefficients are divided into overall coefficients and local coefficients. Local Coefficients give the pressure coefficients for loaded areas of 1 m2 or less e.g. for the design of small elements and fixings; overall coefficients give the pressure coefficients for loaded areas larger than 10 m^2. Net pressure coefficients give the resulting effect of the wind on a structure, structural element or Component per unit area.

Force coefficient

Force coefficients give the overall effect of the wind on a structure, structural element or component as a whole, including friction, if not specifically excluded.

Design situations

(1) The relevant wind actions shall be determined for each design situation identified in accordance with EN 1990.
(2) In accordance with EN 1990, other actions (such as snow, traffic or ice) which will modify the effects due to wind should be taken into account.
(3) In accordance with EN 1990, the changes to the structure during stages of execution (such as different stages of the form of the structure, dynamic characteristics, etc.), which may modify the effects due to wind, should be taken into account.

Wind velocity and velocity pressure

Basis for calculation

(1) The wind velocity and the velocity pressure are composed of a mean and a fluctuating component. The mean wind velocity V_m should be determined from the basic wind velocity V_b which depends on the wind climate, and the height variation of the wind determined from the terrain roughness and orography. The peak velocity pressure is determined .

Basic values

(1)P The fundamental value of the basic wind velocity, vb,0, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10 m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

The basic wind velocity shall be calculated from Expression

$$V_b = C_{dir}\ C_{season}\ ,\ V_{b,0}$$

V_{b0} = fundamental value of basic wind velocity taken as 55 m/s

C_{dir} (recommended value) = 1

C_{season} (recommended value) = 1

Mean wind

Variation with height

(1) The mean wind velocity $V_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, V_b, and should be determined using Expression .

$$V_m(z) = C_r(z) . C_o(z) . V_b$$

where:
$V_m(z)$ is the mean wind velocity at height h above the terrain.
$C_r(z)$ is the roughness factor.
$Cc_o(z)$ is the orography factor, taken as 1,0 unless otherwise specified.
The influence of neighboring structures on the wind velocity should be considered.

Wind pressure on surfaces

(1) The wind pressure acting on the external surfaces, w_e , should be obtained from Expression .

$$W_e = W_p(Z_e) . C_{pe}$$

where:
$q_p(Z_e)$ is the peak velocity pressure
Z_e is the reference height for the external pressure .
c_{pe} is the pressure coefficient for the external pressure.
The wind pressure acting on the internal surfaces of a structure, w_i , should be obtained from Expression

$$w_i = q_p(z_i) . c_{pi}$$

where:
$q_p(zi)$ is the peak velocity pressure
z_i is the reference height for the internal pressure .
c_{pi} is the pressure coefficient for the internal pressure

The net pressure on a wall, roof or element is the difference between the pressures on the opposite surfaces taking due account of their signs. Pressure, directed towards the surface is taken as positive, and suction, directed away from the surface as negative.

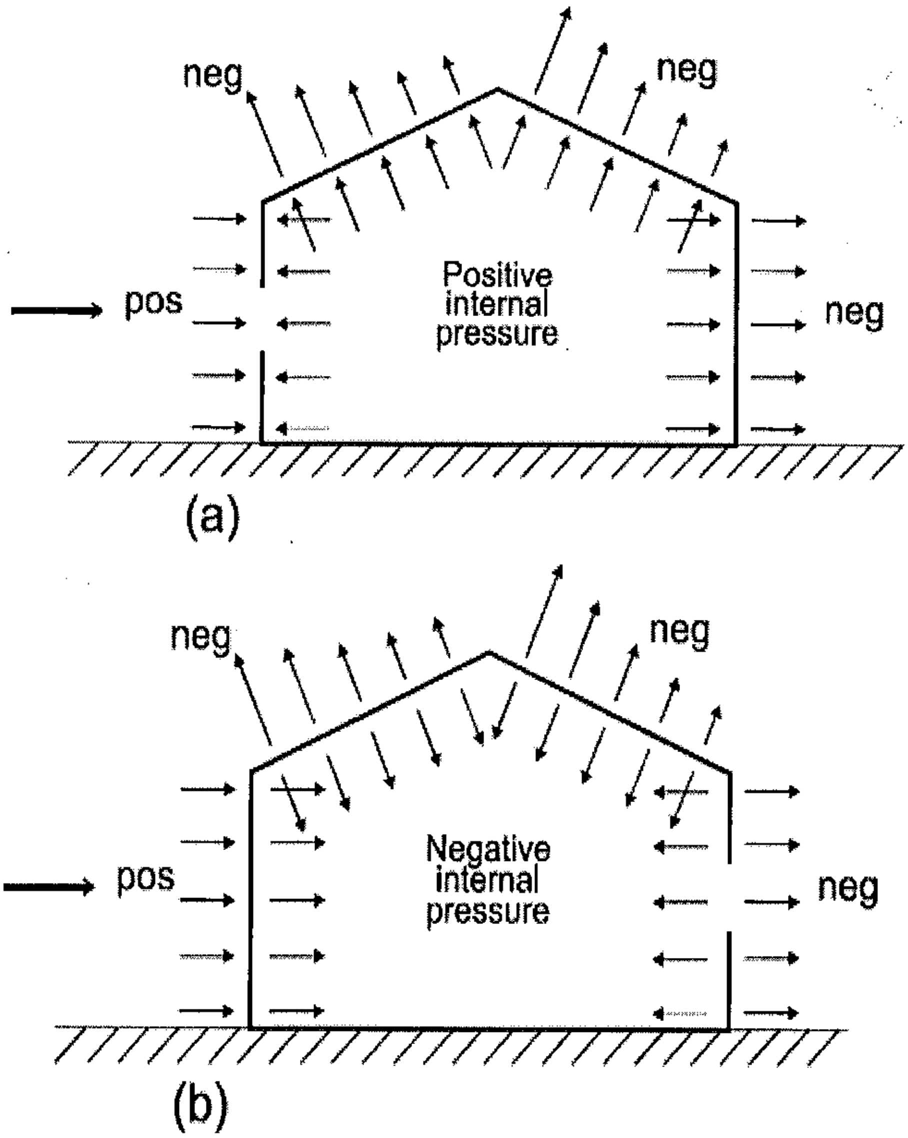
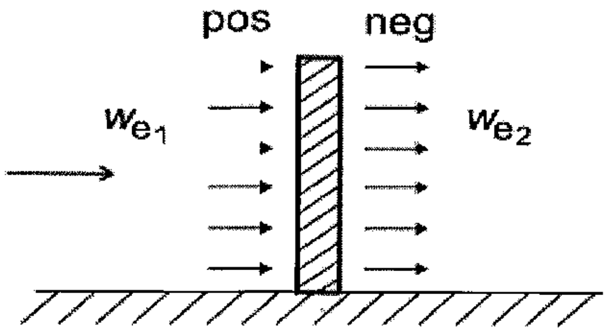
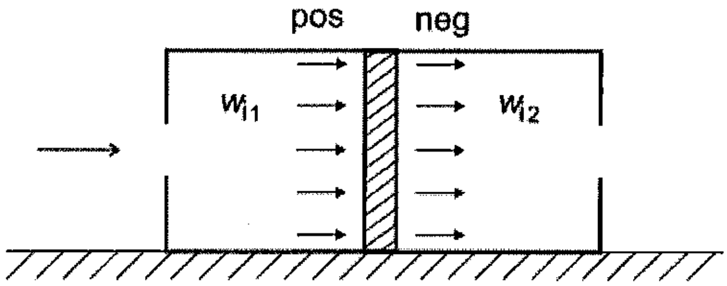

neg
neg
pos
Positive internal pressure
neg
(a)
neg
neg
pos
Negative internal pressure
neg
(b)

Fig. 3



(c)



(d)

Vertical walls of rectangular plan buildings

(1) The reference heights, z_e, for windward walls of rectangular plan buildings depend on the aspect ratio h/b and are always the upper heights of the different parts of the walls. They are given in Figure for the following three cases:

– A building, whose height h is less than b should be considered to be one part.
– A building, whose height h is greater than b, but less than $2b$, may be considered to be two parts, comprising: a lower part extending upwards from the ground by a height equal to b and an upper part consisting of the remainder.
– A building, whose height h is greater than $2b$ may be considered to be in multiple parts, comprising: a lower part extending upwards from the ground by a height equal to b; an upper part extending downwards from the top by a height equal to b and a middle region, between the upper and lower parts, which may be divided into horizontal strips with a

height h_{strip} as shown in Figure 2 .

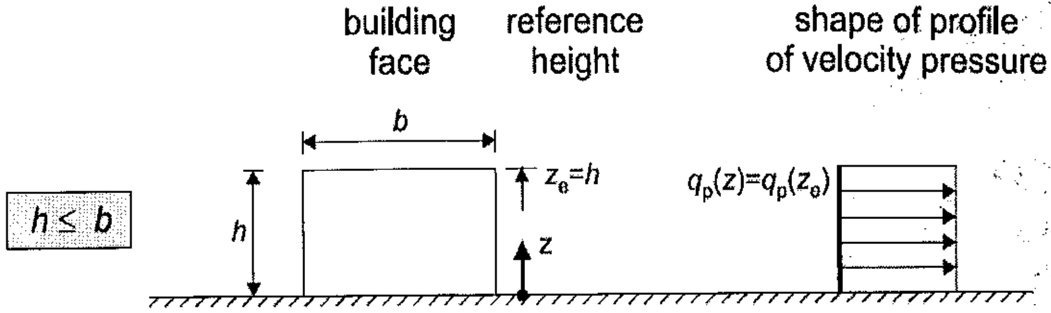
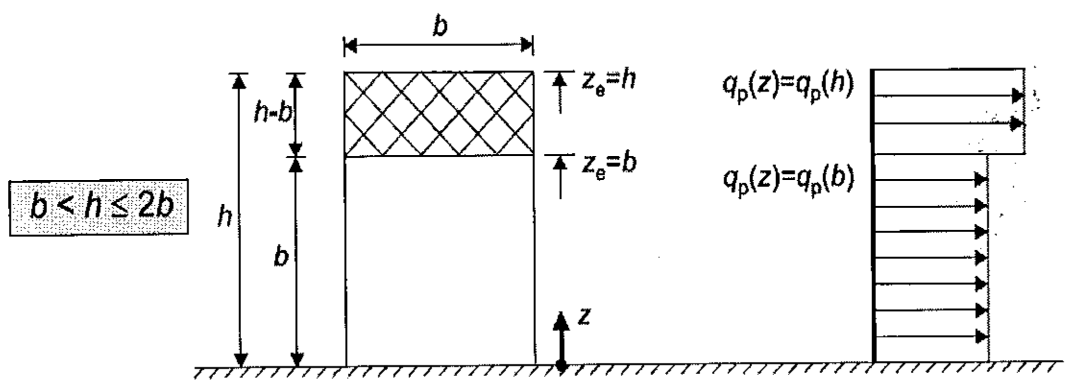
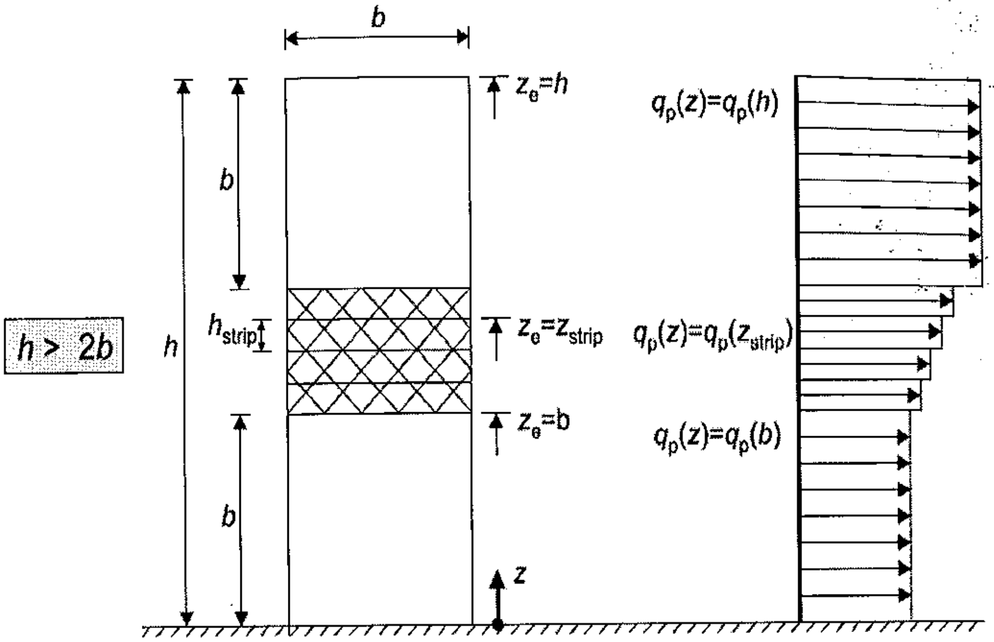


Fig. 4





NOTE The velocity pressure should be assumed to be uniform over each horizontal strip considered.

Reference height, z_e, depending on *h* and *b*, and corresponding velocity pressure profile.

(2) The external pressure coefficients c_{pe}, 10 and c_{pe}, 1 for zone A, B, C, D and E are defined in Figure 1.2.

Table 1 — Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings

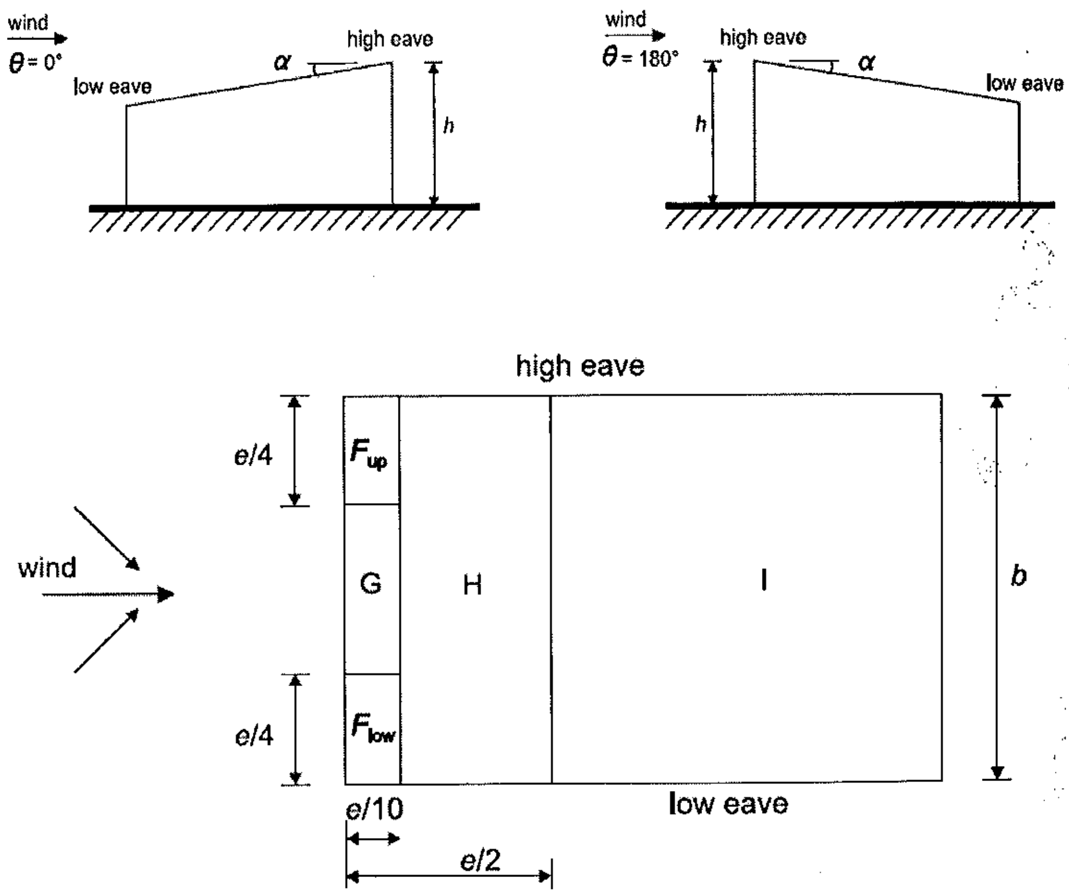
Zone	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

(3) In cases where the wind force on building structures is determined by application of the pressure coefficients *cpe* on windward and leeward side (zones D and E) of the

building simultaneously, the lack of correlation of wind pressures between the windward and leeward side may have to be taken into account.

Monopitch Roofs

(1) The roof, including protruding parts, should be divided into zones .
(2) The reference height z_e should be taken equal to h.
(3) The pressure coefficients for each zone that should be used.



(c) wind direction θ= 90°

Fig. 5

External pressure coefficients for monopitch roofs Table 2

Pitch Angle α	Zone for wind direction $\Theta = 90°$									
	F_{up}		F_{low}		G		H		I	
	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5°	-2,1	-2,6	-2,1	-2,4	-1,8	-2,0	-0,6	-1,2	-0,5	
15°	-2,4	-2,9	-1,6	-2,4	-1,9	-2,5	-0,8	-1,2	-0,7	-1,2
30°	-2,1	-2,9	-1,3	-2,0	-1,5	-2,0	-1,0	-1,3	-0,8	-1,2
45°	-1,5	-2,4	-1,3	-2,0	-1,4	-2,0	-1,0	-1,3	-0,9	-1,2
60°	-1,2	-2,0	-1,2	-2,0	-1,2	-2,0	-1,0	-1,3	-0,7	-1,2
75°	-1,2	-2,0	-1,2	-2,0	-1,2	-2,0	-1,0	-1,3	-0,5	

ASCE 7-98
AMERICA

About ASCE: This standard provides minimum load requirements for the design of buildings and other structures that are subject to building code requirements. Loads and appropriate load combinations, which have been developed to be used together, are set forth for strength design and allowable stress design. For design strengths and allowable stress limits, design specifications for conventional structural materials used in buildings and modifications contained in this standard shall be followed. The structural load requirements provided by this standard are intended for use by architects, structural engineers, and those engaged in prepared and administrating local building codes.

Analytical Design Procedure:

1. The basic wind speed V and wind directionality factor K_d shall be determined.

2. An importance factor I should be determined.

3. An exposure category or exposure categories and velocity pressure exposure coefficient K_Z or K_h for each wind direction.

4. A topographic factor K_v shall be determined.

5. A gust effect factor G or G_f, as applicable, shall be determined.

6. An enclosure classification shall be determined.

7. Internal pressure coefficient $G_{Cp}i$ shall be determined.

8. External pressure coefficients C_p or C_{pf}, or force coefficients C_f, as applicable, shall be determined.

9. Velocity pressure q_z as applicable, shall be determined

10. Design wind load P or F shall be determined.

Exposure Categories:

For each wind direction considered, an exposure category that adequately reflects the characteristics of ground surface irregularities shall be determined for the site at which the building or structure is to be constructed. For a site located in the transition zone between categories, the category resulting in the largest wind forces shall apply. Account shall be taken of variations in ground surface roughness that arises from natural topography and vegetation as well as from constructed features. For any given wind direction, the exposure in which a specific building or other structure is sited shall be assessed as being one of the following categories:

1. Exposure A: A Large city centers with at least 50% of the buildings having a height in excess of 70 ft (21.3 m). Use of this exposure category shall be limited to those areas for which terrain representative of Exposure A prevails in the upwind direction for a distance of at least 0.8 km or 10 times the height of the building or other structure, whichever is greater. Possible channeling effects or increased velocity pressures due to the building or structure being located in the wake of adjacent buildings shall be taken into account.

2. Exposure B: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single- family dwellings or larger. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of at least 1,500 ft (460 m) or 10 times the height of the building or other structure, whichever is greater.

3. Exposure C: Open terrain with scattered obstructions having heights generally less than 9.1 m. This category includes flat open country, grasslands and shorelines in hurricane prone regions.

4. Exposure D: Flat, unobstructed areas exposed to wind flowing over open water (excluding shorelines in hurricane prone regions) for a distance of at least 1.61 km. Shorelines in exposure D include inland waterways, the Great Lakes and coastal areas of California, Oregon, Washington and Alaska. This exposure shall apply only to those buildings and other structures exposed to the wind coming from over the water. Exposure D extends inland from the shoreline a distance of 1,500 ft (460 m) or 10 times the height of the building or structure, whichever is greater.

Velocity pressure exposure coefficient:

It is based on exposure category. Velocity pressure exposure coefficient K_z shall be determined.

Topographic effect:

Wind Speed-Up over hills, ridges, and escarpment:

Wind speed-up effects at isolated hills, ridges, and escarpments constituting abrupt changes in the general topography, located in any exposure category, and shall be included in the design when buildings and other site conditions and locations of structures meet all of the following conditions:
1. The bill, ridge, or escarpment is isolated and unobstructed upwind by other similar topographic features of comparable height for 100 times the height of the topographic feature (100 h) or 3.22 km, whichever is less. This distance shall be measured

horizontally from the point at which the height H of the hill, ridge. Or escarpment is determined.

2. The hill, ridge, or escarpment protrudes above the height of upwind terrain features within 3.22 km radius in any quadrant by a factor of two or more.

3. H/La greater than or equal to 0.2 and

4. H is greater than or equal to 15 ft (4.5 m) for Exposures C and D and 60 ft (18 m) for exposures A and B.

Topographic factor: The wind speed-up effect shall be included in the calculation of design wind loads by using the factor

$$K_v = (1 + K_1K_2K_3)^2$$

Velocity Pressure: Velocity pressure q_z evaluated at a height z shall be calculated by the following equation:

$$q_z = 0.613K_zK_DK_UV^2 \text{ (N/m}^2\text{)}$$

Where

K_D = wind directionality factor

K_Z = velocity pressure exposure coefficient

K_U = topographic factor

q_z = velocity pressure calculated at mean root height h.

The numerical coefficient .613 shall be used except where sufficient climatic data are available to justify the selection of a different value of this factor for a design application.

Design wind pressure for low rise buildings:

Design wind pressure for the main wind force resisting system of low rise buildings shall be determined by the following equation:

$$P = q_h\ [(GC_{pf})\ \text{(N/mm}^2\text{)}$$

Where:

q_h= velocity pressure evaluated at a mean root height h
(GC_{pf})= external pressure coefficients.

AIJ Japan Wind Codes

Wind Loads

Each wind load is determined by a probabilistic-statistical method based on the concept of "equivalent static wind load", on the assumption that structural frames and components/cladding behave elastically in strong wind. Mean wind force based un the mean wind speed and fluctuating wind force based on fluctuating flow field act on a building. The effect of fluctuating wind force on a building or part thereof depends not only on the characteristics of fluctuating wind force but also on the size and vibration characteristics of the buildings or part thereof. These recommendations evaluate the maximum loading effect on a building due to fluctuating wind force by a probabilistic-statistical method and calculate the static wind load that gives the equivalent effect. The design wind load can be obtained from the summation of this equivalent static wind load and mean wind load.

Wind load on structural frames and wind loads on components/cladding

The wind loads provided in these recommendations is composed of those for structural frames and those for component/cladding. The former are for the design of structural frames and such as columns and beams. The latter are for the design of finishing and bedding members of components/cladding and their joints. Wind loads on structural frames are calculated on the basis of the elastic response of the whole building against fluctuating wind forces. Wind loads on components/cladding are calculated on the basis of fluctuating wind forces acting on a small part.

Wind Force coefficients and wind pressure coefficients

Wind force coefficients and wind pressure coefficients fall into two categories corresponding to the design of structural frames and components/claddings. The coefficients shall be estimated from wind tunnel experiments or from the following procedures using wind pressure coefficients (external & internal pressure coefficients)

Procedure for estimating Wind Force Coefficients

1. Wind force coefficients for design of structural frames

2. Wind force coefficients for estimating horizontal wind loads on structural frames

3. Wind force coefficients are calculated using the external pressure coefficients.

Roof wind load on structural frames

Roof wind load on structural frames are calculated from:

$$W_R = q_H C_R G_R A_R$$

Where,

W_R (N): Wind load

q_H (N/m^2): Design velocity pressure defined

C_R : Wind force coefficient as defined

G_R : Gust effect for roof wind load as defined

A_R (m^2): Subject area

The design velocity pressure, q_H (N/m^2),is calculated from:

$$q_H = \frac{1}{2}\rho . U_H{}^2$$

Where,

ρ (kg/m^3): air density assumed

U_H (m/s): design wind speed which depends upon wind direction

Design Wind speed(U_H), is calculated for each wind direction from:

$$U_H = U_0 K_D E_H K_{R,W}$$

Where,

U_0: Basic wind speed (m/s) depending on geographic location of the construction site, as defined

K_D: Wind directionality factor as defined

E_H : Wind speed profile factor at reference height H defined

$K_{R,W}$: Return period conversation factor

Wind speed profile factor

Wind speed profile factor E is calculated from:

$$E = E_R E_G$$

Where,

E_R : Exposure factor for flat terrain categories

E_G : Topography factor defined

Exposure factor based on flat terrain categories

$$E_R : 1.7\ (Z/Z_G)^{\alpha}$$

Where,

Z(m) : height above ground

Z_G, α : Parameters determining the exposure factor

Wind force coefficients for estimating roof wind loads on structural frames

Wind force coefficients are calculated using the external pressure coefficients and the internal pressure coefficients:

$$C_d = C_{pe1} - C_{pe2}$$

Where,

C_{pe1}: External pressure coefficients on windward side

C_{pe2} : External pressure coefficients on leeward side

Australian/ New Zealand code AS/NZS 1170.2002

This joint Australian/ New Zealand standard was prepared by joint technical committee BD-006, general design requirement and loading on structures. It was approved on behalf of council of standard Australian on 29th march 2002 and on behalf of council standard New Zealand on March 28th 2002. It was published on 4th June 2002, this standard maybe used as a means for demonstrating compliance with the requirement of Part (B) of building code of Australia.

AS/NZS 1170.2-Part 2 is used for calculation of wind load. This standard sets out procedure for determining wind speeds and resulting wind action to be used in structural design of structures subjected to wind actions other than those caused by tornadoes. the standard covers the structures within the following criteria :

1. Buildings less than 20 m high.
2. Structures with roof span less than 100 m.
3. Structures other than of shore structures and bridges.

Design Wind pressure and distributed forces

The Wind pressure (p) in Pascal shall be determined for structures and part of structures as follows:

$$P=(.5Q_{air})\,[V_d]^2.C_{fig}.C_{dyn}$$

Where:

P = Design wind pressure(Pa).
Q_{air} = Density of air, 1.2 kg/m^3.
V_d = Buliding orthogonal, design wind speed taken as 40 m/s.
C_{fig} = Aerodynamic shape factor.
C_{dyn} = dynamic response factor, generally value is taken as 1.

Aerodynamic shape factor

$$C_{fig} = C_{pe}.K_a.k_c.k_i.k_p$$

Where :

Cpe = external pressure coefficient (-.4).
K_a = Area reduction factor (.8).
K_c = combination factor (.8).
K_i = local pressure (1).
K_p = porous gradient (1).

Area Reduction Factor (K_a)

For roofs and side walls the area reduction factor shall be given in table for all other cases. It shall be taken as 1, tributary area is the area contributing to the force being considered.

Table 3

Tributary Area (A) ,m^2	Area Reduction Factor(K_a)
<= 10	1.0
25	.9
>= 100	.8

NOTE : For intermediate values of A, use linear interpolation.

Combination Factor (K_c)

Where wind pressures acting on two or more surfaces of an enclosed building e.g. Windward wall, upwind roof, side walls etc contribute simultaneously to a structural action effect on a major structural element, the combination factor given in table may be applied to the combined forces calculated for critical external and internal surfaces. This factor shall not be applied to cladding or immediate supporting structures such as purling.

Permeable Cladding Reduction Factor (K_p)

The Permeable Cladding Reduction Factor shall be taken as 1 except that where an external surface consists of Permeable cladding and solidity ratio is less than .999 and exceed .99.The solidity ratio of the surface is the ratio of the solid areas to total area of the surface.

PERMEABLE CLADDING REDUCTION FACTOR (K_p)

Horizontal distance from windward edge (see Note)	K_p
0 to $0.2d_s$	0.9
$0.2d_s$ to $0.4d_s$	0.8
$0.4d_s$ to $0.8d_s$	0.7
$0.8d_s$ to $1.0d_s$	0.8

NOTE: d_s is the along-wind depth of the surface in metres.

Table 4

CHAPTER – 3

COMPARISON

BETWEEN

CODES

COMPARISON BETWEEN IS-875-3 AND AIJ

1) In IS 875 probability factor terrain height factor and topography factor are taken into account for design wind speed where as in AIJ air density is used for calculating design velocity pressure.

2) In AIJ gust effect factor is used for calculating wind load where as IS 875 in IS 875 it is not used.

3) In AIJ for calculating roof wind load different parameter like design wind speed, wind direction factor, wind speed profile factor, topographic factor, return period conversion factor were used, which makes the designing difficult and sometimes erroneous if not done meticulously where as in IS 875 it is quite easy.

4) In IS 875 there is separate table for pressure coefficient at wind angle of 0 and 90 degree but in AIJ there is no table for pressure coefficient at 90 degree wind angle.

COMPARISION BETWEEN IS 875-3 AND EURO CODE

1) In IS 875 basic wind velocity is determined simply from the figure applicable to 10 meter height whereas in EURO code basic wind velocity depends upon various parameters like fundamental value of basic wind velocity directional factor and seasonal factor.

2) In IS 875 there is a separate table for internal pressure coefficient where as in EURO code internal pressure coefficient is taken 0.75 of external pressure coefficient.

3) In IS 875 force on the cladding is directly obtained from the formulas given in the code whereas in EURO CODE, pressure on the cladding is obtained and it is then multiplied by cladding area to get the force.

4) In EURO code terrain category is given more stress in calculating basic wind speed than in IS 875.

COMPARISON BETWEEN IS-875-3 AND AS/NZS

1) In AS\NZS aerodynamic factor is used to take into account the effect of external coefficient, area, pressure by incorporating different parameters like area reduction factor, combination factor, local pressure factor etc. in it, whereas in IS 875-3 design wind speed accounts for such parameters.

2) In AS\NZS a special factor called permeable cladding reduction factor is used in case the cladding is not divided into sections while calculating the forces, only windward & leeward sides were considered.

COMPARISON BETWEEN IS 875-3 AND ASCE

1) In ASCE some new factors like wind directionality factor, importance factor etc. are used which is not used in IS 875-3.

2) In IS 875-3 for obtaining pressure coefficient table are given only for 0 & 90 degree wind angle whereas in ASCE tables for range of angles 0 to 45 degree & 45 to 90 degree are given which covers the entire range of attacking wing angle.

3) Like IS 875-3, in ASCE the cladding is divided among four sections for calculating force with slight variations.

CHAPTER 4

NUMERICAL

IS 875-3

Design wind speed

$V_z = v_b k_1 k_2 k_3$

Roof Angle (a) = 30 degrees

V_b = basic wind speed, taken as 55 m/s

K_1 = probability factor, from table k_1 = .89

K_2 = terrain height, structure size factor, from table = 1.05

Taking class A, terrain category-1 at height 6 m

Considering upwind slope less than 3 degree,

$K_3 = 1$

Hence,

Building ht. Ratio	Roof Angle	Wind angle 0	
		EF	GH
h/w< (1/2)	30	-.5	-.5

Design wind speed = 55*. 89*1.05*1

= 51.39 m/sec

Design wind pressure $p_a = .6v_z^2$

= 1584.55 N/m^2

h\w < (1\2) = .46

from table 3

Force (F) = $C_{pe}\ AP_a$

Area = 137.8 m^2

FORCE	Wind angle 0 degree	
	-109.175	-109.175

EURO CODE

Wind pressure on external surface

$We = q_p\ (z_e).\ c_{pe}$

Where:

$q_p(ze)$ is the peak velocity pressure

z_e is the reference height for the external pressure

c_{pe} is the pressure coefficient for the external pressure,

now,

basic wind velocity

$V_b = C_{dir} C_{season} V_{bo}$

V_{b0} = fundamental value of basic wind velocity taken as 55 m/s

V_{b0}= recommended value = 1

C_{season} recommended value = 1

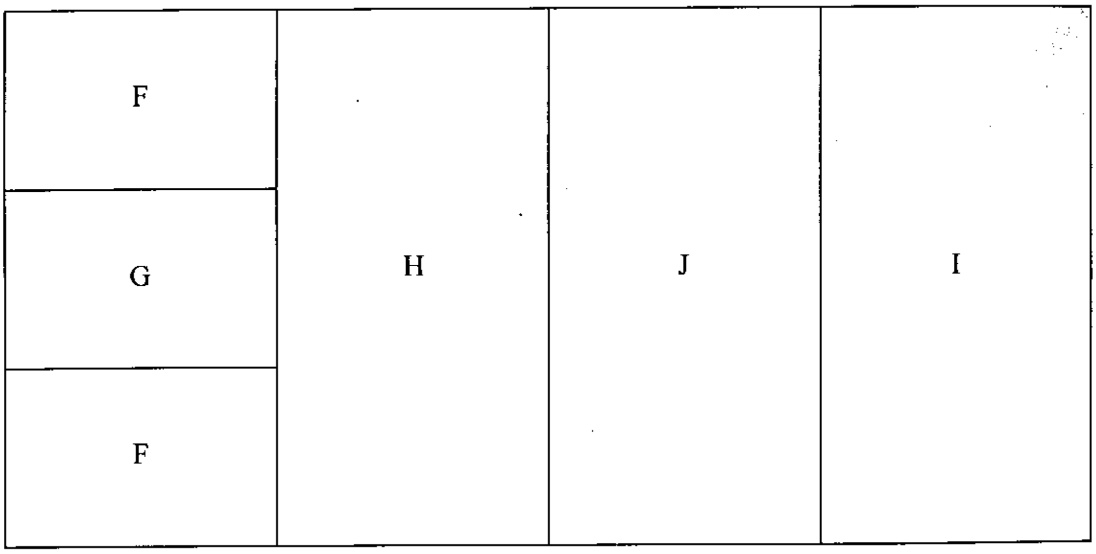
So, $V_b = 1*1*55 = 55$m/sec

Peak velocity pressure

$q_{p(z)} = c_{e(z)} q_b$ & $q_b = (1/2) V_b^2 \rho$

so, q_b = 1845.25 m/sec

hence, $q_{p(z)}$ = 3321.45 N/m^2



Pressure coefficient for $\theta = 0$ degree.

	F	G	H
Coeff.	-2.5	-1.3	-.9

FORCE	Windward		
	-71.085	-85.90	-110.02

AIJ JAPAN

Roof wind loads on structural frames are calculated from

$W_R = q_H C_R G_R A_R$

W_R (N): wind load

q_H (n/m^2): design velocity pressure

C_R: wind force coefficient

G_R: gust factor for roof wind load

A_R (m^2): subject area

The design velocity pressure, Q_H (N/m), is calculated from:

$QH=(1\backslash 2)p.U_H^2$

Where,

p (kg/m^3): air density, assumed to be

U_H(m/s): design wind speed, which depends on wind direction

Design wind speed, U_H (m/s), is calculated for each wind direction from:

$U_H = U_0 K_D E_H K_{RW}$

where

U_0: basic wind speed (m/s) depending on the geographic location of the construction site,

K_D: wind directionality factor

E_H: wind speed profile factor at reference height H defined

K_{RW}: return period conversion factor

Wind speed profile factor:
Wind speed profile factor E is calculated from:

$E = E_R E_G$

Where,

E_R: exposure factor for flat terrain categories

E_G : topography factor defined

Exposure factor based on flat terrain categories

E_R: 1.7 $(Z\backslash Z_G)^a$

Z (m): height above ground

Z_B, a: parameters determining the exposure factor

So, E_R= 0.99

E_G= 1, K_{RW} = 3.9

U_H = 55*.85*.99*3.9 = 180.50

So, $q_h = 0.5*1.22*(180.50)^2 = 19873.95$ N

FORCE	WINDWARD R_U	
	(+ve)KN	(-ve)KN
	84.125	-62.54

AS\NZS

Design wind pressure

P= $(.5Q_{air})\ [v_d,o]^2 .\ C_{fig}.\ C_{dyn}$

P = design wind pressure (Pascal's)

Q_{air} = density of air, 1.2 kg/m^3

V_D = building orthogonal; design wind speed taken as 55 m/sec

C_{fig} = aerodynamic shape factor

C_{dyn} = dynamic response factor (generally value is taken as 1)

Aerodynamic shape factor

$C_{fig} = C_{pe}.K_a.K_c.K_p.K_i$

Where,

C_{pe} = external pressure coefficient (.4) from table

K_a = area reduction factor (.8) from table

K_c = combination factor (.8) from table

K_i = local pressure factor (1)

K_p = porous cladding (1)

C_{fig} = -.4*.8*.8*1*1

= -.256

P = $(.5\ Q_{air})\ [V_{d,\theta}]2.C_{fig}.C_{dyn}$

P=$.5*1.2*(55)^2*(-0.256*1)$

= 46.4 KN

ASCE

Design wind pressure

$P = q_h (GC_{pf})$

q_h = velocity pressure

GC_{pf} = External pressure coefficient

So,

$q_h = .613k_z.k_{zt}.k_d.V^2$

k_d = wind directionality factor (0.85) from table

k_z = velocity exposure factor, from table

$k_z = 2.01\ (Z/Z_g)^{2/\alpha}$

$\alpha = 9.5$,

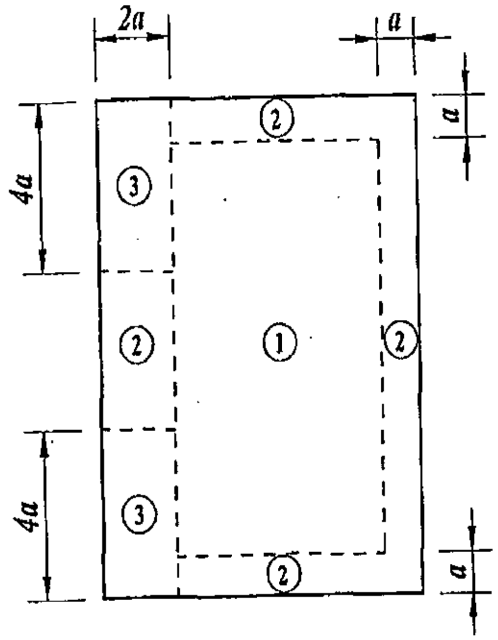
$Z = 20$, $Z_g = 900$

Hence, $k_z = 0.901$

V = 55 m/sec,

a = 10 % of horizontal distance = 1.54

So, $q_h = 0.613*0.901*1*0.85*(55)^2$

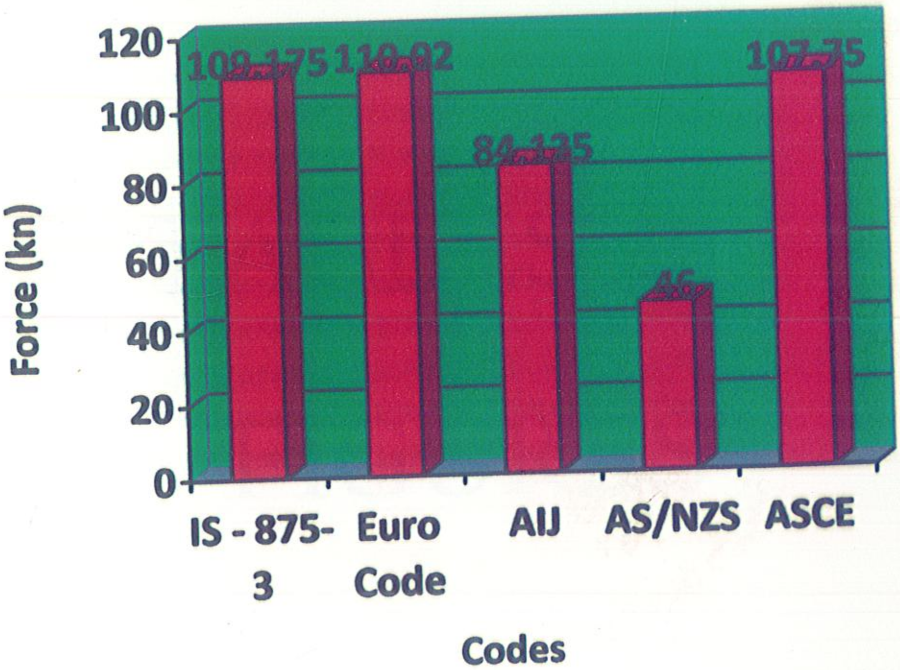


CASE	1	2	3
Coefficient	-1.1	-1.2	-2
Pressure	-1562.14	-1704.15	-2840.26
Area (m^2)	47.43	52.175	37.94
Force (kN)	-74.092	-88.91	-107.75

CHAPTER – 5

CONCLUSION

1) The design value for IS 875-3 is max, & AS/NZS is min., it means that, construction of a wind resistance building according to AS/NZS is most economical and by IS 875-3 is least economical whereas by other codes is moderately economical.
2) The design procedure fro Indian code is easy and straight whereas in other codes the design procedures are lengthy and difficult.
3) In ASCE & EURO CODE design pressure is obtained from the formula whereas design force is obtained in other codes.
4) Unlike other codes, in AIJ the basic wind speed depends largely on frequency of tornadoes & coastal winds.



BAR CHART

TABLES and FIGURES

IS -875

CALCULATION OF PROBABILITY FACTOR (K1) Table 5

Class of Structure	Mean Probable Design Life of Structure in Years	k_1 Factor for Basic Wind Speed (m/s) of					
		33	39	44	47	50	55
All general buildings and structures	50	1·0	1·0	1·0	1·0	1·0	1·0
Temporary sheds, structures such as those used during construction operations (for example, form-work and falsework), structures during construction stages and boundary walls	5	0·82	0·76	0·73	0·71	0·70	0·67
Buildings and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings	25	0·94	0·92	0·91	0·90	0·90	0·89
Important buildings and structures such as hospitals communication buildings / towers, power plant structures	100	1·05	1·06	1·07	1·07	1·08	1·08

CALCULATION OF K2 Table 6

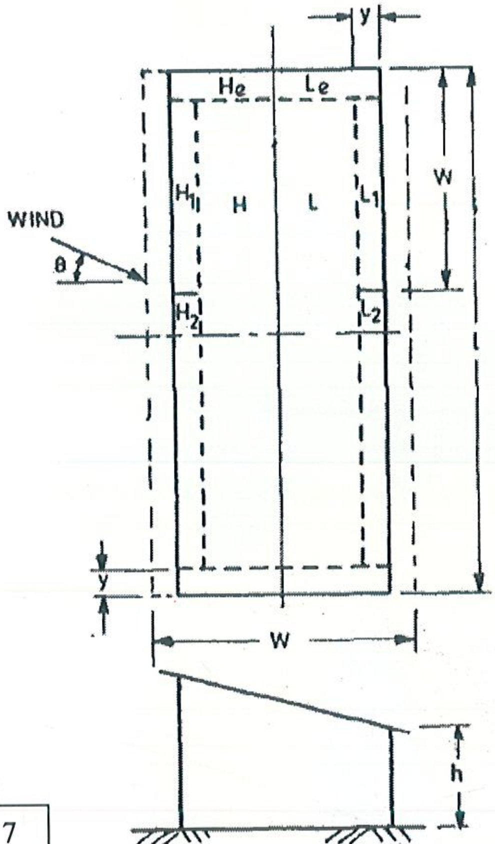
TABLE 2 k_2 FACTORS TO OBTAIN DESIGN WIND SPEED VARIATION WITH HEIGHT IN DIFFERENT TERRAINS FOR DIFFERENT CLASSES OF BUILDINGS/STRUCTURES

(*Clause* 5.3.2.2)

Height	Terrain Category 1 Class			Terrain Category 2 Class			Terrain Category 3 Class			Terrain Category 4 Class		
m	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
10	1·05	1·03	0·99	1·00	0·98	0·93	0·91	0·88	0·82	0·80	0·76	0·67
15	1·09	1·07	1·03	1·05	1·02	0·97	0·97	0·94	0·87	0·80	0·76	0·67
20	1·12	1·10	1·06	1·07	1·05	1·00	1·01	0·98	0·91	0·80	0·76	0·67
30	1·15	1·13	1·09	1·12	1·10	1·04	1·06	1·03	0·96	0·97	0·93	0·83
50	1·20	1·18	1·14	1·17	1·15	1·10	1·12	1·09	1·02	1·10	1·05	0·95
100	1·26	1·24	1·20	1·24	1·22	1·17	1·20	1·17	1·10	1·20	1·15	1·05
150	1·30	1·28	1·24	1·28	1·25	1·21	1·24	1·21	1·15	1·24	1·20	1·10
200	1·32	1·30	1·26	1·30	1·28	1·24	1·27	1·24	1·18	1·27	1·22	1·13
250	1·34	1·32	1·28	1·32	1·31	1·26	1·29	1·26	1·20	1·28	1·24	1·16
300	1·35	1·34	1·30	1·34	1 32	1·28	1·31	1·28	1·22	1·30	1·26	1·17
350	1·37	1·35	1·31	1·36	1·34	1·29	1·32	1·30	1·24	1·31	1·27	1·19
400	1·38	1·36	1·32	1·37	1·35	1·30	1·34	1·31	1·25	1·32	1·28	1·20
450	1·39	1·37	1·33	1·38	1·36	1·31	1·35	1·32	1·26	1·33	1·29	1·21
500	1·40	1·38	1·34	1·39	1·37	1·32	1·36	1·33	1·28	1·34	1·30	1·22

TABLE 6 EXTERNAL PRESSURE COEFFICIENTS (C_{pe}) FOR MONOSLOPE ROOFS FOR RECTANGULAR CLAD BUILDINGS WITH $\frac{h}{w} < 2$

(*Clause* 6.2.2.3)



y = *h* or 0·15 *w*, whichever is the lesser.

Table 7

Roof Angle α	Wind Angle θ										Local C_{pe}					
	0°		45°		90°		135°		180°							
Degree	*H*	*L*	*H*	*L*	*H* & *L* (Applies to length *w*/2 from windward end)	*H* & *L* (Applies to remainder)	*H*	*L*	*H*	*L*	H_1	H_2	L_1	L_2	*He*	*Le*
5	−1·0	−0·5	−1·0	−0·9	−1·0	−0·5	−0·9	−1·0	−0·5	−1·0	−2·0	−1·5	−2·0	−1·5	−2·0	−2·0
10	−1·0	−0·5	−1·0	−0·8	−1·0	−0·5	−0·8	−1·0	−0·4	−1·0	−2·0	−1·5	−2·0	−1·5	−2·0	−2·0
15	−0·9	−0·5	−1·0	−0·7	−1·0	−0·5	−0·6	−1·0	−0·3	−1·0	−1·8	−0·9	−1·8	−1·4	−2·0	−2·0
20	−0·8	−0·5	−1·0	−0·6	−0·9	−0·5	−0·5	−1·0	−0·2	−1·0	−1·8	−0·8	−1·8	−1·4	−2·0	−2·0
25	−0·7	−0·5	−1·0	−0·6	−0·8	−0·5	−0·3	−0·9	−0·1	−0·9	−1·8	−0·7	−0·9	−0·9	−2·0	−2·0
30	−0·5	−0·5	−1·0	−0·6	−0·8	−0·5	−0·1	−0·6	0	−0·6	−1·8	−0·3	−0·5	−0·5	−2·0	−2·0

NOTE — *h* is the height to eaves at lower side, *l* is the greater horizontal dimension of a building and *w* is the lesser horizontal dimension of a building.

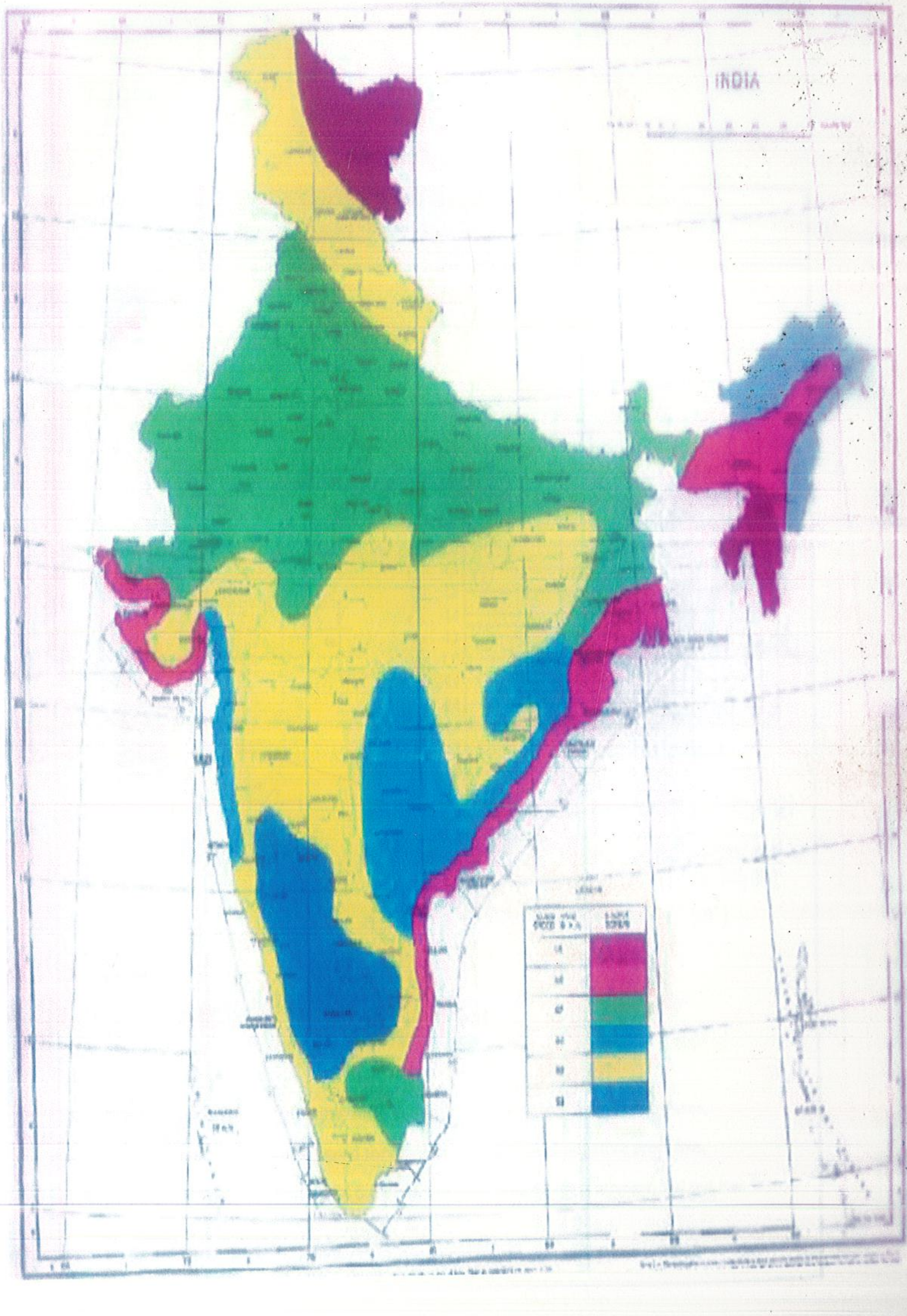
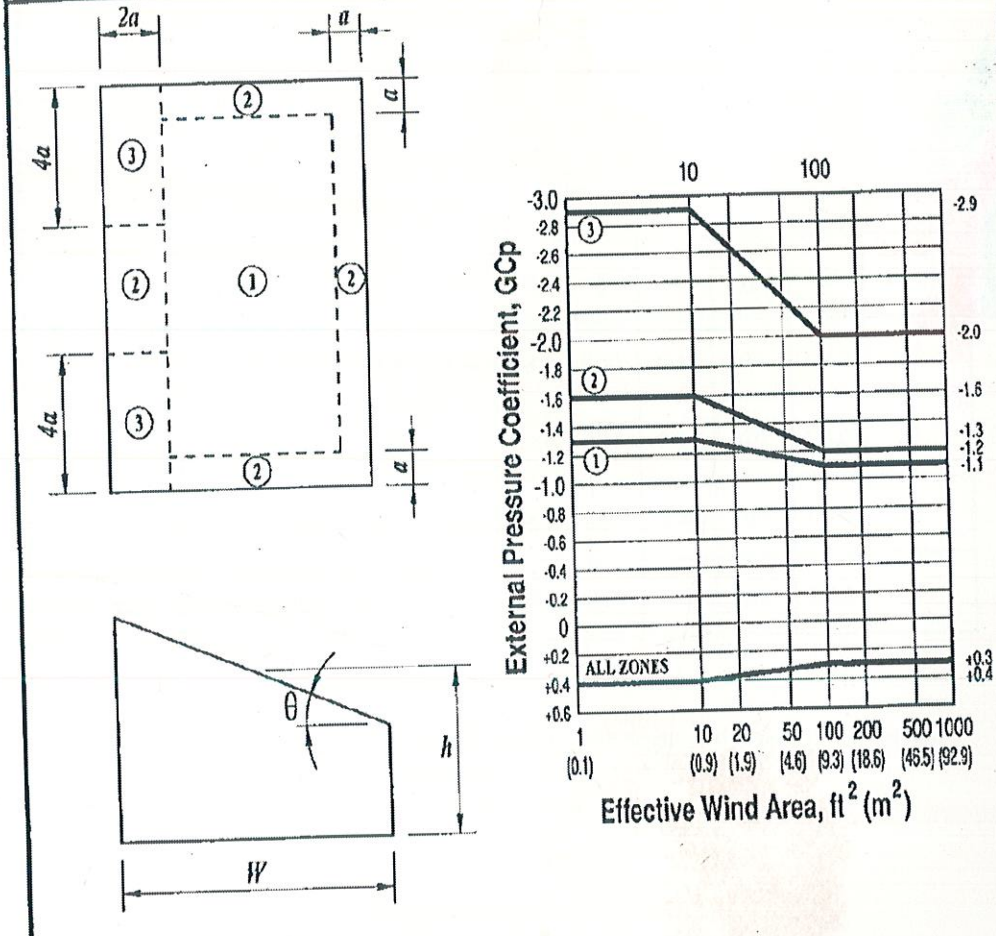

INDIA

Fig. 6

Components and Cladding		h ≤ 60 ft.
Figure 6-7A (con't)	External Pressure Coefficients, GC_p	Monoslope Roofs $10° < \theta \le 30°$
Enclosed, Partially Enclosed Buildings		



Notes:

1. Vertical scale denotes GC_p to be used with q_h.
2. Horizontal scale denotes effective wind area A, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively
4. Each component shall be designed for maximum positive and negative pressures.
5. Notation:
   - a: 10 percent of least horizontal dimension or $0.4h$, whichever is smaller, but not less than either 4 percent of least horizontal dimension or 3 ft (1 m).
   - h: Mean roof height, in feet (meters).
   - W: Building width, in feet (meters).
   - θ: Angle of plane of roof from horizontal, in degrees.

Table 8

Terrain Exposure Constants

Table 6-4

Exposure	α	z_g (ft)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)*
A	5.0	1500	1/5	0.64	1/3.0	0.30	0.45	180	1/2.0	60
B	7.0	1200	1/7	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

*z_{min} = minimum height used to ensure that the equivalent height $\bar{z}$ is greater of $0.6h$ or z_{min}. For buildings with $h \le z_{min}$, $\bar{z}$ shall be taken as z_{min}.

Table 9

Wind Directionality Factor, K_d

Table 6-6

Structure Type	Directionality Factor K_d*
Buildings **Main Wind Force Resisting System** **Components and Cladding**	 0.85 0.85
Arched Roofs	0.85
Chimneys, Tanks, and Similar Structures **Square** **Hexagonal** **Round**	 0.90 0.95 0.95
Solid Signs	0.85
Open Signs and Lattice Framework	0.85
Trussed Towers **Triangular, square, rectangular** **All other cross sections**	 0.85 0.95

*Directionality Factor K_d has been calibrated with combinations of loads specified in Section 2. This factor shall only be applied when used in conjunction with load combinations specified in 2.3 and 2.4.

Main Wind Force Resisting System		All h
Figure 6-3 (con't)	External Pressure Coefficients, C_p	Walls & Roofs
Enclosed, Partially Enclosed Buildings		

Wall Pressure Coefficients, C_p			
Surface	L/B	C_p	Use With
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h
	2	-0.3	
	≥4	-0.2	
Side Wall	All values	-0.7	q_h

Roof Pressure Coefficients, C_p, for use with q_h

Wind Direction	Windward									Leeward		
	Angle, θ (degrees)									Angle, θ (degrees)		
	h/L	10	15	20	25	30	35	45	≥60#	10	15	≥20
Normal to ridge for θ ≥ 10°	≤0.25	-0.7	-0.5 0.0*	-0.3 0.2	-0.2 0.3	-0.2 0.3	0.0* 0.4	0.4	0.01 θ	-0.3	-0.5	-0.6
	0.5	-0.9	-0.7	0.4 0.0*	-0.3 0.2	-0.2 0.2	-0.2 0.3	0.0* 0.4	0.01 θ	-0.5	-0.5	-0.6
	≥1.0	-1.3**	-1.0	-0.7	-0.5 0.0*	-0.3 0.2	-0.2 0.2	0.0* 0.3	0.01 θ	-0.7	-0.6	-0.6

Wind Direction	h/L	Horiz distance from windward edge	C_p
Normal to ridge for θ < 10 and Parallel to ridge for all θ	≤ 0.5	0 to h/2	-0.9
		h/2 to h	-0.9
		h to 2 h	-0.5
		> 2h	-0.3
	≥ 1.0	0 to h/2	-1.3**
		> h/2	-0.7

*Value is provided for interpolation purposes.

**Value can be reduced linearly with area over which it is applicable as follows

Area (sq ft)	Reduction Factor
≤ 100 (9.29 sq m)	1.0
200 (23.23 sq m)	0.9
≥ 1000 (92.9 sq m)	0.8

Notes:

1. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively
2. Linear interpolation is permitted for values of *L/B*, *h/L* and θ other than shown. Interpolation shall only be carried out between values of the same sign. Where no value of the same sign is given, assume 0.0 for interpolation purposes.
3. Where two values of C_p are listed, this indicates that the windward roof slope is subjected to either positive or negative pressures and the roof structure shall be designed for both conditions. Interpolation for intermediate ratios of h/L in this case shall only be carried out between C_p values of like sign.
4. For monoslope roofs, entire roof surface is either a windward or leeward surface.
5. For flexible buildings use appropriate G_f as determined by rational analysis.
6. Refer to Table 6-8 for arched roofs.
7. Notation:
   - *B*: Horizontal dimension of building, in feet (meter), measured normal to wind direction.
   - *L*: Horizontal dimension of building, in feet (meter), measured parallel to wind direction.
   - *h*: Mean roof height in feet (meters), except that eave height shall be used for θ ≤ 10 degrees.
   - *z*: Height above ground, in feet (meters).
   - *G*: Gust effect factor.
   - q_z, q_h: Velocity pressure, in pounds per square foot (N/m²), evaluated at respective height.
   - θ: Angle of plane of roof from horizontal, in degrees.
8. For mansard roofs, the top horizontal surface and leeward inclined surface shall be treated as leeward surfaces from the table.

#For roof slopes greater than 80°, use $C_p = 0.8$

Table 10

Table 11

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
The terrain categories are illustrated in Annex A.1.			

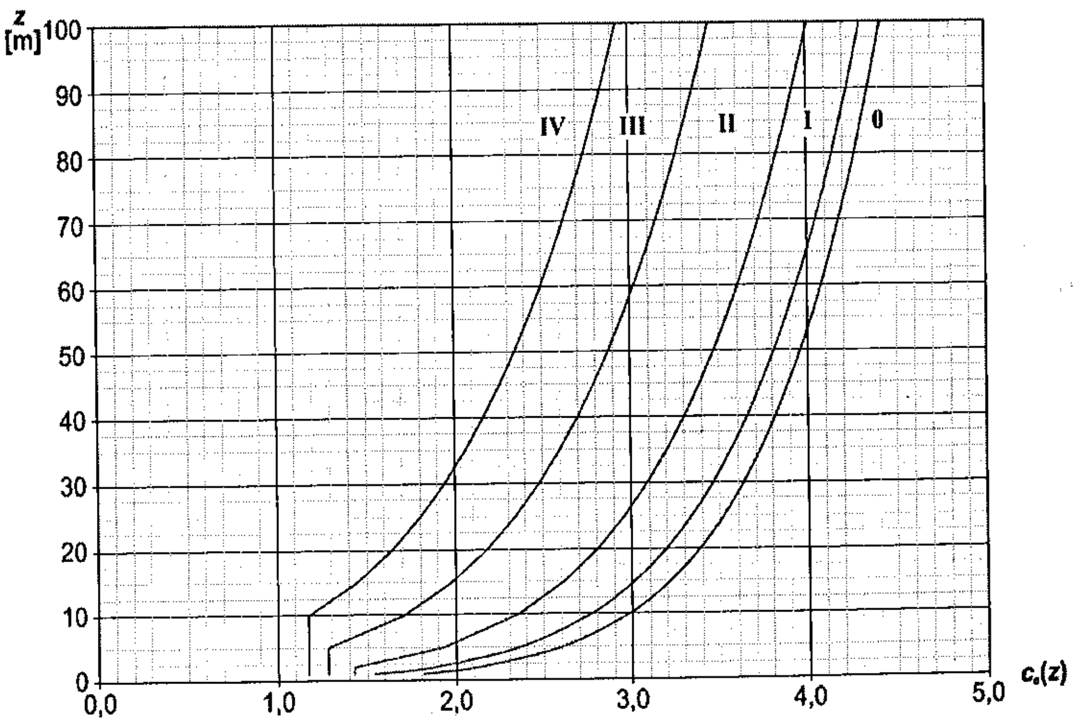


Fig. 7

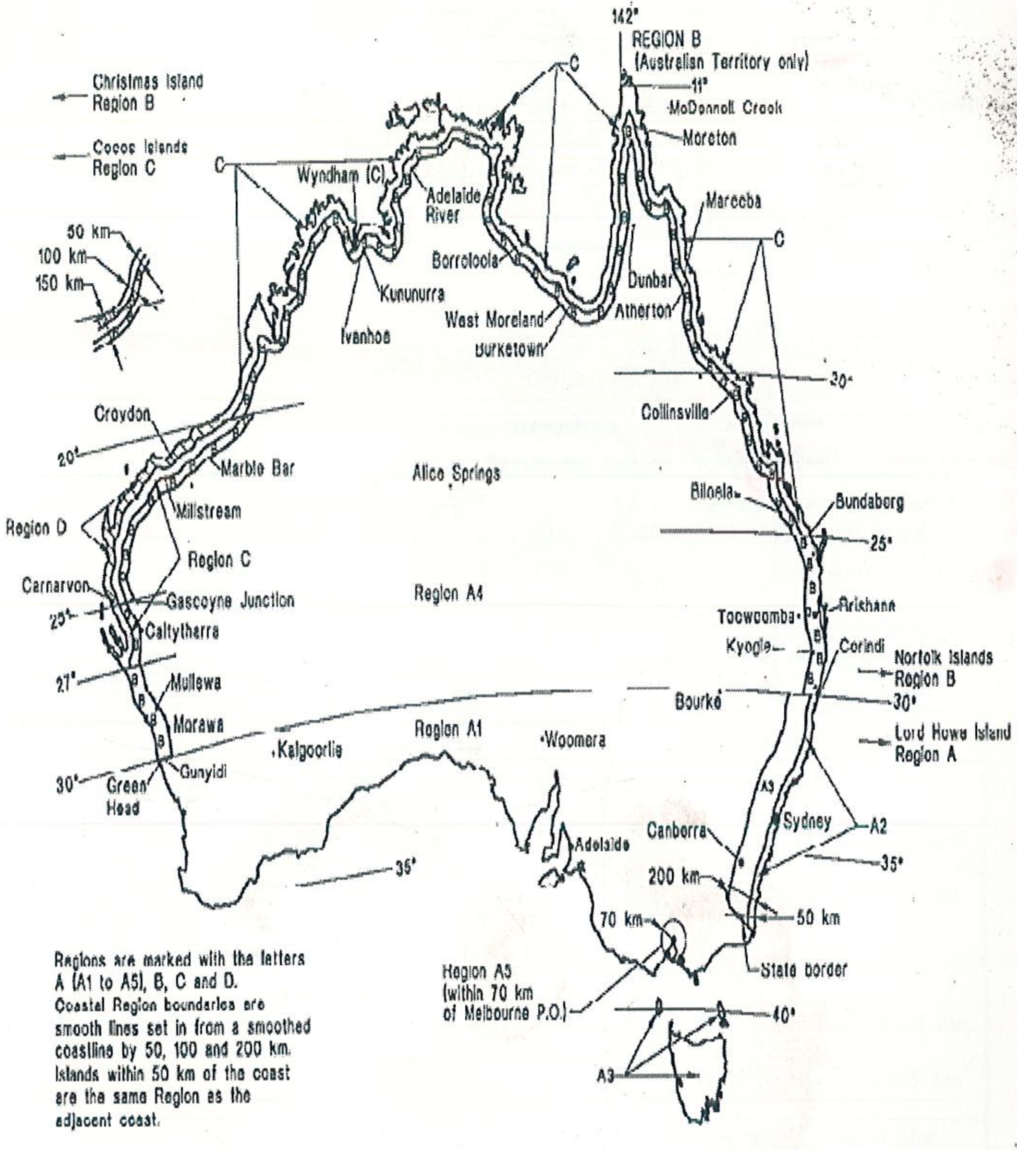
Table 12

Pitch Angle α	Zone for wind direction $\Theta = 0°$						Zone for wind direction $\Theta = 180°$					
	F		G		H		F		G		H	
	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5°	-1,7	-2,5	-1,2	-2,0	-0,6	-1,2	-2,3	-2,5	-1,3	-2,0	-0,8	-1,2
	+0,0		+0,0		+0,0							
15°	-0,9	-2,0	-0,8	-1,5	-0,3		-2,5	-2,8	-1,3	-2,0	-0,9	-1,2
	+0,2		+0,2		+ 0,2							
30°	-0,5	-1,5	-0,5	-1,5	-0,2		-1,1	-2,3	-0,8	-1,5	-0,8	
	+0,7		+0,7		+0,4							
45°	-0,0		-0,0		-0,0		-0,6	-1,3	-0,5		-0,7	
	+0,7		+0,7		+0,6							
60°	+0,7		+0,7		+0,7		-0,5	-1,0	-0,5		-0,5	
75°	+0,8		+0,8		+0,8		-0,5	-1,0	-0,5		-0,5	

AIJ JAPAN

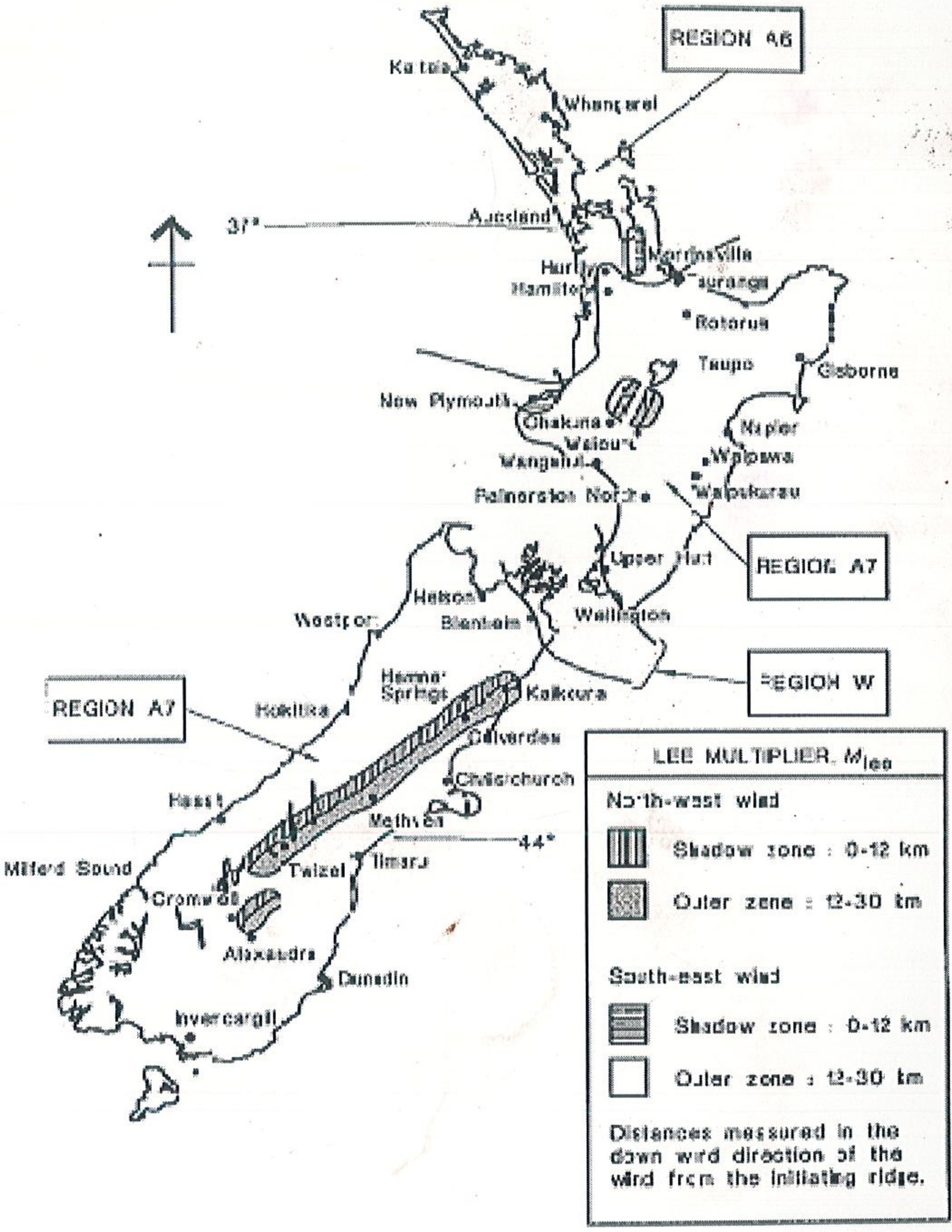
	Category	Condition at construction site and upwind region
Smooth	I	Open, no significant obstruction, sea, lake
↑	II	Open. few obstructions, grassland, agricultural field
	III	Suburban, wooded terrain, few tall buildings (4 to 9-story)
↓	IV	City, tall buildings (4 to 9-story)
Rough	V	City. heavy concentration of tall buildings (higher than 10-story)

Fig. 7



(a) Australia

Fig. 8


REGION A6
Kaitaia
Whangarei
37°
Auckland
Huntly
Morrinsville
Hamilton
Tauranga
Rotorua
Taupo
Gisborne
New Plymouth
Ohakune
Waiouru
Wanganui
Napier
Waipawa
Waipukurau
Palmerston North
Upper Hutt
REGION A7
Nelson
Westport
Blenheim
Wellington
REGION W
Hanmer Springs
Kaikoura
REGION A7
Hokitika
Culverden
Christchurch
Haast
Methven
44°
Milford Sound
Twizel
Timaru
Cromwell
Alexandra
Dunedin
Invercargill
LEE MULTIPLIER, M_{lee}
North-west wind
Shadow zone : 0-12 km
Outer zone : 12-30 km
South-east wind
Shadow zone : 0-12 km
Outer zone : 12-30 km
Distances measured in the down wind direction of the wind from the initiating ridge.